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THE FIRST DYNAMOMETER CAR OF THE GERMAN DEMOCRATIC REPUBLIC

Eng P. Kalinowski
Eng H. Erler

For objective judgment of a steam locomotive, its mechanical and thermal quantities must be known, besides its dimensions and weight. Stationary testing plants have been built in foreign countries, but these fail to take into account actual operating conditions on the line, which conditions vary markedly. A dynamometer car, on the other hand, makes it possible to run tests under actual operating conditions.

After World War II, the German Reichsbahn was left with none but the remnants of two dynamometer cars. Now, the first postwar dynamometer car has been reconstructed from these remnants. The following is a description of this dynamometer car and the way in which its measuring devices function.

I. MEASUREMENT OF MECHANICAL MAGNITUDES

Drawbar Pull and Work

The force exerted at the drawbar is not only decisive for locomotive performance, but its generation is the whole purpose of the locomotive. The drawbar pull is measured by a fluid dynamometer inserted in the drawbar of the dynamometer car, in which a plunger presses against a rubber diaphragm with a force that varies with the force acting on the drawbar. This diaphragm covers a chamber filled with glycerine water. The fluid pressure thus produced is registered on a manometer in the dynamometer car, with a scale calibrated in kilograms of drawbar pull. The range of the dynamometer and the manometer goes up to 22 tons.

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As a rule, the purpose is to measure the force acting on the drawbar of the tender, thus including the dynamometer car; but in measuring the rolling resistance of the cars, only the forces acting behind the dynamometer car are to be determined. The special construction of the apparatus for measuring drawbar pull allows the force required for moving the dynamometer car itself to be excluded from such measurements.

Since the inaccuracy of the apparatus for measuring drawbar pull is relatively high when the drawbar pull is small, a small dynamometer for measurements up to 6 tons is inserted in the drawbar between the instrument car and the locomotive being tested. This dynamometer has interchangeable plungers of varying size so that even the smallest amount of drawbar pull can be determined with great precision by using the proper plunger. The manometer for the small dynamometer has a scale calibrated in kilograms per square centimeter, and the drawbar pull is calculated by multiplying the manometer reading by a coefficient corresponding to the plunger used.

But the drawbar pull is not only shown but currently registered as well. For this purpose a Bourdon tube is attached to each of the two dynamometers, parallel to the manometers. Each tube is coupled to a registering mechanism that records the drawbar pull on a tape, in relation to the distance traveled. The tape is advanced by a gearing actuated ultimately by the motion of the central axle of the three-axle truck under the instrument room. While the wheels of the two outer sets of wheels have the usual conical profile, the wheels of the metering axle are cylindrical and unflanged. In this way, a uniform forward motion, corresponding to the distance traveled, is imparted to the tape. To reduce the amount of wear, the set of wheels used for measuring is not braked.

The integral of the drawbar pull over the distance traveled represents the work on the drawbar. To avoid having to trace manually on a planimeter the drawbar-pull curves recorded on the tape, which would involve loss of accuracy and time, there is an automatic integrating planimeter for each dynamometer.

When the Bourdon tube stretches, it actuates not only the recording mechanism but also the counting roll of the planimeter by diverting it, by means of a lever, from the center of a disk. This disk is actuated by the metering axle. At drawbar pull $Z = 0$, the roll is exactly at the center of the disk. It cannot rotate, even when a fairly long distance has been traveled. Only when the drawbar pull increases, the actuating gear of the counting mechanism leaves the center. The work performed on the drawbar is calculated by multiplying the planimeter value by a constant determined from calibration of Bourdon tubes and planimeters.

Velocity, Time, and Distance Traveled

The dynamometer car has two speedometers, one indicating and the other registering, used respectively for observation and recording of the speed. They, too, are actuated by the metering axle. Both instruments, build as eddy-current tachometers, have been specially designed for the dynamometer car. The recording speedometer carries a roll instead of a pointer on its vertical pointer shaft. A thread passes over this roll and over a roll on the other side of the recording tape and moves a small slide with a glass stylus that records the speed.

Besides the mechanical values mentioned, time must also be registered on the tape if the experimental results are to be interpreted. A stylus actuated by a contact clock [a clockwork circuit breaker] makes marks on the tape at one-second intervals, omitting every tenth mark to facilitate counting. The same

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stylus also register by strokes toward the opposite side of the tape, kilometer marks, special station marks, and places where indicator diagrams have been taken. The meaning of the marks is filled on the tape by hand.

The kilometer indicator at the side of the instrument table shows on an interchangeable itinerary strip the position of the car on the line at any given moment, together with the profile of the line. The metering axle drives a horizontal spindle which moves a pointer over the itinerary, thus showing the position of the car on the line. Before the beginning of the test, it is decided at what points along the line the instruments on the locomotive and in the dynamometer car shall be read or indicator diagrams taken. When these points are reached, acoustic signals are automatically sounded on the locomotive being tested and in the dynamometer car, so that readings of all instruments can be taken at the same time.

Supplementary Equipment

All measurements must be taken under steady conditions if data satisfactory for comparison is to be obtained; that is, speed, cylinder cutoff, and steam-chest pressure must all be kept constant. The inclusion of the starting and braking distances in the measurements makes the results inexact The proportion of starting ar braking distances to total distance traveled is exceptionally high for high-speed runs under constant conditions. The dynamometer car is therefore equipped with a device to make a "flying start" possible so as to exclude the values during starting and braking from the final results. Magnetic couplings in the route-feed gearing of the planimeters and in the gearing of the counters for distance traveled under steam, time traveled under steam, and water consumed make it possible to measure work at the drawbar, distance and time traveled under steam, and water consumed during the period the train is running at the planned constant speed. At a signal from the locomotive, all couplings are engaged by the action of a toggle switch. When the constant-speed run is to be terminated, all the counter couplings are again simultaneously disengaged. Independently of this process of engaging and disengaging, however, drawbar pull, speed, time, and water consumption are continuously recorded throughout the trip. The beginning and end of the test run are noted on the recording tape.

Another auxiliary device allows accelerations and decelerations to be determined with extraordinary precision. For every half revolution of the wheel, a contact mechanism, actuated by the central set of wheels of the three-axle truck, makes a mark on a tape, which is advanced at uniform speed. The notched marks showing the time required for each half revolution of the wheel are longer or shorter, according to the speed of the train. At high speeds, the impulses are no longer given directly by the central set of wheels but are geared down so that the length between strokes of the stylus can be made to correspond to distances traveled of 20, 40, 100, 500, or 1,000 meters by simply changing the gear ratio. This device also makes it possible to determine positively at the end of the run whether or not the speed was entirely uniform on all sections of the run. The notches have the same length at constant speed. Particular attention should be paid to this circumstance in making measurements of the rolling resistance of vehicles.

II. MEASUREMENT OF THERMAL FACTORS

The measurement of drawbar pull, performance, and speed, as just discussed, would be entirely sufficient for a quantitative appraisal of the locomotive. During recent decades, however, more emphasis has been laid on the economical operation of the steam locomotive, and great importance was attached to the improvement of its operating efficiency; accordingly, the scope of test measurements was extended to include also those factors required for a qualitative

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judgment. For this, besides the consumption data for coal and water, we must also know the temperatures of feed water, steam, and combustion gases, together with the composition of the combustion gases. The indicator diagram gives information about the processes inside the cylinder.

Water and Coal Consumption

The amount of feed water required is registered on the recording tape in 50-liter units. A water meter, installed on the locomotive behind the injector, has a contact mechanism that transmits the necessary current impulses for recording the water consumption. The latter can also be read off directly from the counter of the water meter. Since, in addition to this, the water in the tender is measured at the beginning and end of every test run, the amount of water consumed can be determined with sufficient accuracy.

Unfortunately the same cannot be said of coal consumption. It is true that the amount of coal conveyed to the grate during the test run can be weighed, but it is necessary to estimate the amount of coal on the grate at the beginning and end of the run, and to take into consideration, in so doing, the extent to which that coal has burned down at these respective times.

At the end of the test, ashes and clinkers are weighed. The steam consumption of the air pump is determined from the number of strokes, using a calibration curve. These strokes are electrically transmitted from the locomotive to a counting mechanism in the dynamometer car.

Time and Distance Traveled Under Steam; Indicator Diagrams

To measure the time traveled under steam, the dynamometer car is equipped with a clock, the magnetic stop mechanism of which is released only when the throttle is open. The distance traveled, in meters, is simultaneously transmitted to a counter, which is likewise switched on and off by the throttle contact.

Indicator diagrams are taken by special indicators constructed for locomotive operation. In locomotive testing, as compared with stationary installations, there is the difficulty that the indicators are not accessible during the test period. For this reason, the stylus arm and feed of the diagram paper must be actuated by remote control. In the indicators used at present, this is done electromagnetically from the car of the locomotive being tested. Only the adjustment cocks for taking diagrams in front of the piston or behind it are mechanically controlled.

Temperature Measurements

Special attention is paid to temperature measurements. The temperature of the steam is taken at various points. The temperature of the superheated steam furnishes information about the efficiency of the superheater, while the difference between temperature at admission to the cylinders and temperature at exhaust from them represents the change of enthalpy and, consequently, the amount of heat which has been transformed into mechanical work. Feed-water temperatures are measured before and after passing through the preheater. They characterize the quality of the preheater; the temperature after the preheater (feed-water temperature at induction into the boiler) is necessary, like the temperature of the superheated steam, for calculating boiler efficiency. Temperatures in the smokebox are measured at at least three points. Excessive temperatures here may be ascribed to poor heat transfer from the combustion gases to the boiler and superheater and necessarily imply high smokestack losses.

Temperatures are measured by the principle of measuring electrical resistance. This is based on the well-known phenomenon that the ohmic resistance of a conductor changes with its temperature. A resistance thermometer consists essentially of a platinum spiral fused into quartz glass and protected from damage by casing. The platinum spirals used in the dynamometer car have a resistance of 50 ohms at 0 degrees centigrade. The temperatures are shown by a Wheatstone bridge. Two indicating devices with electrodynamometers are available to obtain the readings. Their range is up to 300 and 600 degrees centigrade, respectively. The instruments are switched to the various measurement points by means of switches. The temperatures most important for interpretation of the tests are recorded continuously by two six-color recording instruments. Temperatures from 12 points can be automatically registered.

Combustion Gas Analysis

The combustion gas is examined by two different devices, an Orsat apparatus and a combustion-gas tester. The combustion gas to be examined is pumped to the instrument car. Part of it is collected in a rubber bag and analyzed with an Orsat apparatus at the conclusion of each test section. While this analysis gives average values for a longer period, the combustion-gas tester continuously shows the composition of the combustion gases, which can be read off on two indicators, showing respectively percent of CO_2 and percent of $CO + H_2$. Both these values are also registered on a two-curve recording apparatus.

Other Measurements

Measurements of the pressure in the boiler and the steam chest, and, in compound locomotives, in the connector as well, also belong to the group of thermal measurements.

To appraise the induced draft equipment, the partial vacuum in the ash pan, firebox and smokebox, and the blast-pipe pressure, are all shown in the locomotive cab and are noted by observers there, together with other important test data, including valve-gear data

In addition to the devices described here, the dynamometer car is also equipped with a number of other instruments which may, at first thought, seem unimportant, but, nevertheless, allow the measurement of factors which prove indispensable for more detailed study and interpretation.

A flow meter is built into the steam main to measure the amount of steam used for heating in the winter. Pressure is measured upstream and downstream of an orifice plate, and the velocity of the steam flow, and, consequently, also the amount of steam, is deduced from the difference between these pressures.

The strength and direction of the wind is measured by a cup anemometer, and a mercurial barometer is provided to determine the atmospheric pressure. The temperature in the firebox is determined by a radiation pyrometer, while those in the journals and bearings are measured by a contact pyrometer.

III. CALIBRATION OF THE EQUIPMENT TO MEASURE DRAWBAR PULL

Dynamometers, manometers, and planimeters must be calibrated before being placed in service, and they must be checked for accuracy at frequent intervals. In calibrating the large dynamometer, the drawbar pull is replaced by a force generated hydraulically. For calibration purposes, the dynamometer is subjected to varying load levels. Simultaneously, readings of the test yoke and

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drawbar-pull manometer are taken, together with the diagram height, which is measured by hand on the recording tape, and the planimeter reading, in which case, the planimeter driving gear is activated by hand. The result of these measurements is embodied in a calibration curve.

On the abscissa of the calibration curve, the drawbar-pull diagram height in millimeters (determined with the aid of the planimeter) is entered, while the ordinate shows the number of kilograms of drawbar pull corresponding to one millimeter of diagram height at each load-level. The calibration curve indicates that the inaccuracy of the drawbar pull meter increases considerably for values below about 2 tons. For this reason, as already noted, a dynamometer with a smaller range is used for measuring smaller drawbar pull. This small dynamometer is calibrated by suspending it from a crane and applying weights.

The other instruments are also calibrated and are checked for accuracy at intervals of a few months.

IV. PECULIARITIES OF CAR CONSTRUCTION

While the exterior of the dynamometer car body is hardly different from the ordinary express-train car, it is still possible to tell the special purpose of the car from the presence of different trucks, one with two axles and the other with three, including the metering axle in the middle. The instrument room and an adjacent conference room take up more than half the entire car. The instrument table is so arranged that the technicians engaged in reading the instruments are not disturbed by visitors, although ample room is provided for a considerable number of visitors. In the conference room, the test data are studied and interpreted. There is also a compartment with two comfortable benches that can be made up into beds at night. The car also has a small workshop and a washroom.

This first dynamometer car of the German Democratic Republic was put in service in November 1950.

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